MEASURE AND ANALYSIS OF A GAZE POSITION USING INFRARED LIGHT TECHNIQUE

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ABSTRACT **We are interested in identifying the object or area that attracts the subject's attention in images. A computer system is developed to measure and analyze the eye position. Eye movements are recorded using an infrared light device. Our interest is concentrated mainly on the calibration of the system, more precisely, on the correction of measured data according to user's characteristics. Higher polynomial transformation is used to model the mapping between eye coordinates and image coordinates. The mean quadratic error criteria is used. This paper presents how our model works to correct the non-linearities in the oculomotor for individual subject's eyes. It also proposes a method to correct head movements.**

Keywords: eye movement, gaze tracking, visual scan path, spatial mapping.

INTRODUCTION

The eye gaze tracking has been used for clinical purposes to detect illnesses, such as nystagmus, unusual eye movements and many others [1][2][3]. It is also used as computer interface to provide disabled people, who cannot use their hands, with a means of communication and environmental control [4][5][6]. In this study we are interested to know where a person is looking and what object attract his attention during visual perception and recognition of an image.

It is known that during visual perception and recognition, human eyes move and successively fixate at most informative parts of the image. The measurement of the direction of the gaze, and spatial mapping of these measures over the displayed image, are the most sensitive methods to gauge the subject's attention in the image, and to describe the scanning strategies. To record the eye movements, this study uses the commercially available device (IRIS system, commercialized by SKALAR) based on infrared reflection technique [7]. As for any measurement system, the measures are affected by noise. The noise is due to human factors, such as head movements and fatigue, and also to instrumental factors like non-linearity of sensor and digitization. Our main interest, in this study, is to correct the measurement data relative to subject's characteristics, by performing a calibration. The calibration procedure is set at the beginning of each experiment. During it, the subject follows a pre-assigned dots with his gaze. From the tracking responses, a polynomial transformation is used to link the subsequent responses to calibration points.

In this paper we first introduce our method by describing the hardware, the calibration procedure and the spatial mapping. Then we give some applications of our system and results.

METHODS

A. System Hardware

Our hardware system consists of personal computer witch is used to collect, calibrate, and analyze the eye movements. The screen is used to displays the image and the stimulation dots.

The subject is seated at 60 centimeters in front of the screen, with his head stabilized by optometric structure and chin rest. The eye movements are recorded using IRIS system, which measures eye position, by using pulsed infrared light. The sensing device, composed of an infrared light emitting diodes and phototransistor detectors, is positioned in front of each eye. The horizontal eye movements (x-coordinates) are recorded from the right eye, and the vertical eye movements (y-coordinates) are recorded from the left eye. The analog outputs from each eye are sampled, at frequency of 500Hz, by a 12 bits digital interface board.

B. Calibration Procedures

The Eye-Track monitor allows calibration through electronic adjustment of offset and gain, using potentiometers. After the initial manual adjustments have been made, the subject is asked to look at series of dots displayed on screen at different locations. The calibration dots are selected to cover uniformly the screen surface. Twenty-five points, in 5x5 grid on the screen, are displayed successively. The points are 7cm apart, and their size is of 5mm, which subtend 0.5deg of visual angle from where the subject is seated (distance of 60 cm). Each point must be fixed during long enough period for the position data to dominate the noise. However a long fixation will be tedious for the subject and may involve other human factors, such as fatigue. According to the study of eye movements, this period must be higher than 200ms [8]. Several periods are tested, and we find that periods higher than one second

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provide us with better results (figure 1). Thus, a period of 2 seconds is selected, which gives duration of 50 seconds for all the calibration procedure.

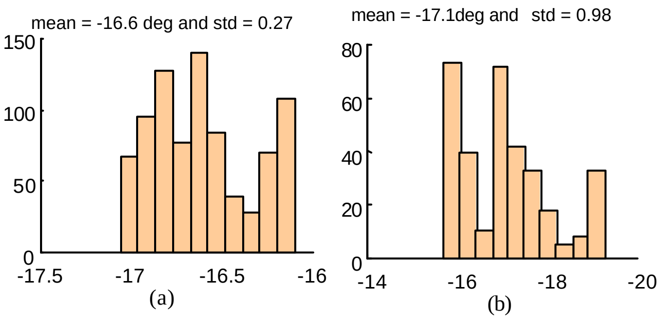


Figure 1 *Distribution of horizontal eye position during fixation; (a) for duration of 2 seconds; (b) for duration of 1second.*

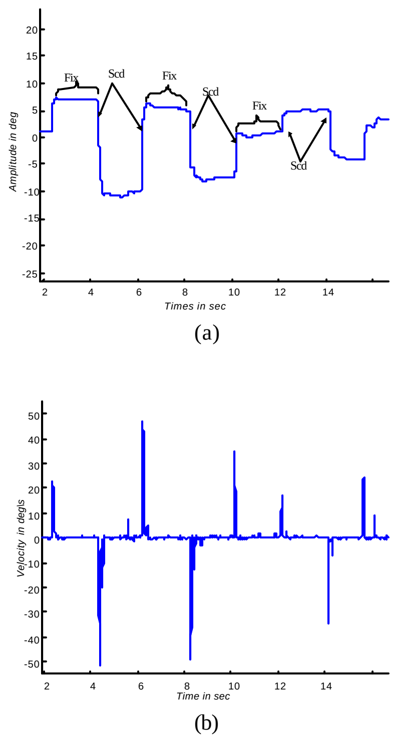


Figure 2

(a) A typical recording of horizontal eye movement during calibration trial. The trace shows (1) saccades (Scd); and (2) fixation periods (Fix).

(b) The trace shows the velocity of the recording horizontal eye movement. Compared to fixation periods the saccade movement presents a greater velocity. Threshold of 5 deg/s is used to distinguish fixation locus from saccades.

A fixation analysis algorithm [9] is then applied to eye movement's data to extract rapid saccade jumps from location of eye fixation. The algorithm, based upon velocity threshold, detects the beginning and the end of a fixation period (figure2). The mean values of fixation locus are selectively stored. Thus, x and y coordinates of gaze positions are generated. These data are used to generate a pair of mapping equations that relate the coordinate of the gaze-position data to spatially corrected data within the space.

C. *Spatial Mapping*

To make our notation clear we will use *Sx* and *Sy* to denote respectively the arrays of x-coordinates and y-coordinates in the screen. *Ex* and *Ey* will denote the *x* and *y* vectors in the equipment coordinates (*i.e.* measurements of the eye position before correction).

Our purpose is to model the mapping $f:(Ex,Ey)\rightarrow(Sx,Sy)$ from equipment coordinates to screen coordinates by using two higher order polynomial transformations. Namely a generalized equations are given by:

$$\begin{aligned} Sx &= a_0 + \sum_{p=1}^{n}\sum_{i=0}^{p} a_{(i,p)} Ex^{p-i} Ey^{i} \\ Sy &= b_0 + \sum_{p=1}^{n}\sum_{i=0}^{p} b_{(i,p)} Ex^{p-i} Ey^{i} \end{aligned} \qquad (1)$$

Where n is the polynomial order and a_i and b_i are the coefficients. The number of these coefficients is related to the order n (Table 1). For $n = 2$, the second-order equation is:

$$\begin{aligned} Sx &= a_0 + a_1 Ex + a_2 Ey + a_3 Ex^2 + a_4 ExEy + a_5 Ey^2 \\ Sy &= b_0 + b_1 Ex + b_2 Ey + b_3 Ex^2 + b_4 ExEy + b_5 Ey^2 \end{aligned}$$

The equation (1) is considered as an estimate of mapping function *f*. It is based upon the order *n* and weighting coefficients (a_i,b_i). For a given *n*, the polynomial weighting coefficients are chosen to minimize the mean-square error between a set of screen coordinates (*Sx,Sy*) and the polynomial estimates (*Scx,Scy*) for the known equipment coordinates (*Ex,Ey*).

The mean square error is given by the compact form

$$e = (Sx - Ma)^T (Sx - Ma) + (Sy - Mb)^T (Sy - Mb)$$

where *a* and *b* are the coefficient vectors:

$$a^T = [a_0 \quad a_1 \quad . \quad . \quad a_m]$$

$$b^T = [b_0 \quad b_1 \quad . \quad . \quad b_m]$$

$$M = \begin{bmatrix} 1 & Ex_1 & Ey_1 & \cdots & Ex_1^{\,n} & \cdots & Ex_1^{\,n-i} Ey_1^{\,i} & \cdots & Ey_1^{\,n} \\ 1 & Ex_2 & Ey_2 & \cdots & Ex_2^{\,n} & \cdots & Ex_2^{\,n-i} Ey_2^{\,i} & \cdots & Ey_2^{\,n} \\ . & . & . & \cdots & . & \cdots & . & \cdots & . \\ . & . & . & \cdots & . & \cdots & . & \cdots & . \\ 1 & Ex_L & Ey_L & \cdots & Ex_L^{\,n} & \cdots & Ex_L^{\,n-i} Ey_L^{\,i} & \cdots & Ey_L^{\,n} \end{bmatrix}$$

m is the number of polynomial coefficients and *L* the number of calibration points.

The mean square error is minimum for

$$a = M^{-}Sx$$
$$b = M^{-}Sy$$
where M^{-} is inverse of M.

We note that L must be greater than m hence $M^{-} = (M^{T}M)^{-}M^{T}$. In our case $L=25$, thus n is selected inferior or equal to 5.

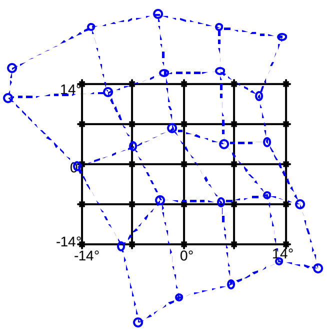
Order	Number of coefficients
2	5
3	9
4	14
5	20

Table 1 *Number of the weighting coefficients of polynomial transformation for the different orders.*

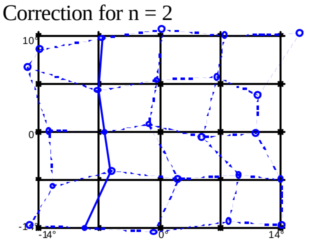
Applications And Results

The spatially corrected calibration is evaluated for several order n. The optimal order and the corresponding optimal coefficients (a_i,b_i) are determined from the best correction (figure 3). These parameters are saved and applied to correct gaze position data

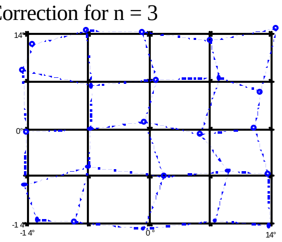
Measured data



Correction for n = 2



Correction for n = 3



Correction for n = 4

Correction for n = 5

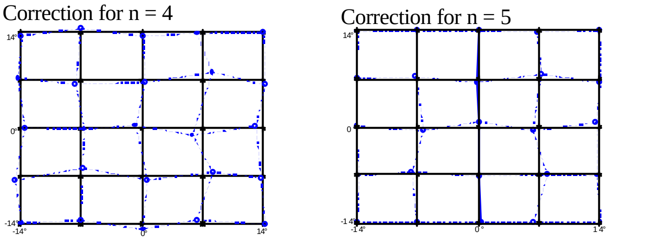


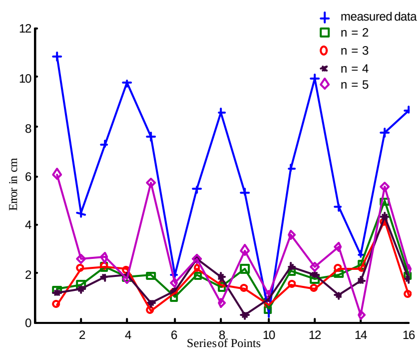
Figure 3

The results of calibration. The solid line presents reference grid and the dash line presents the measured or corrected gaze position. The correction obtained using 5 order polynomial transformation is the best fit.

	Measured data	Corrected data			
		Order 2	Order 3	Order 4	Order 5
Mean square error (deg)	7,2	1,40	1,10	0,68	0,37

Table 2 *Mean square error obtained in calibration step for order 2,3,4,and 5. The optimal order is 5, it presents the lower error (0,37°).*

In order to determine the performance of the calibration procedure, we study a number of tests. Firstly the accuracy is measured when the subject looks at 16 dots distributed on the screen in way to be intermediate to the location of calibration points. Figure 4-a presents the error corresponding to each point calculated using the parameters a_i and b_i estimated for n= 1,2,3,4 and 5 during the calibration step. It appears that the mean square error is minimal for the order 5 and the corresponding coefficients (Table2), However, the results show that the order 4 is optimal with mean error of 1,6° (Figure 4-b). This is due to head movements. Indeed, the tendency to move the head is strong, and small movements are almost impossible to eliminate. Hence, any head movement shifts the axis of the gaze from the true position. So, we introduced this procedure after each trial to correct the variation due to changes in the position of the head.



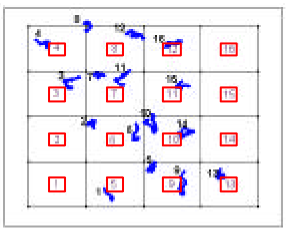
(a)

(b)

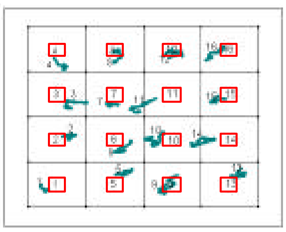
Figure 4

(a) The absolute displacements of the measured and corrected location from the true location.
(b) Mean absolute displacement of measured and corrected location from the true location.

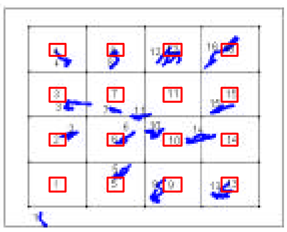
Secondly, we use a square of 2 cm^2 to simulate an object of interest. The subject is told to look at the square that is drawn somewhere in the calibration grid. Sixteen position of square are examined (Figure 5). For each square we acquire a cloud of eye position points. The distance between the center of the square and the center of inertia of the set of points is calculated for the measured and corrected positions. The Table 3 presents the mean distance calculated from the 16 distances for both measured and corrected data. The result shows that the orders 3 and 4 give a similar performance. These results are in agreement with the preceding test.



(a)



(b)



(c)

Figure 5* *Fixation *pattern corresponding to each square.*
(a) measure data; (b) corrected data for n = 4; and (c) corrected data for n = 5.

	Measured position	Corrected position			
		Order 2	Order 3	Order 4	Order 5
Mean distance (deg)	13,28	2,11	1,92	1,95	2,59

Table 3 *Mean distance obtained for measured and corrected data.*

CONCLUSION

In this study, we focus on a method of calibrating the infrared light instrument relative to the user characteristics. Polynomial transformation of higher order is used. The mean quadratic error criteria is used to estimate the optimal transformation parameters. The use of a 5 order polynomial transformation provides the best fit of calibration patterns. However, the application made here shows that 4 order polynomial transformation gives better results than 5 order. This because the subject head is moved from its initial position. Indeed, most recording systems present this problem. In consequence they use some devices to try to immobilize the head like bite boards, chin-rests, and head-rests. But all this equipment can only minimize the movement of the head, a small movement still remains. Therefore, we propose to present to the subject a sequence of dots at the end of each trial. This will be able to help us to better choose the optimal order to use to correct the data. Our perspective is to measure the movement of the head separately to improve the precision of the system. Actually this system is to use to study the craving in nicotine dependent subject. The subjects are evaluated through the shift of attention directed toward significant object in relation to tobacco, when viewing a complex picture. Two kinds of pictures are used: a picture of nicotine cue and picture of neutral cue.

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